Sgluons

Tim M.P. Tait

Work in collaboration with
Tilmino sPlehn

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Outline

- What the heck is a sgluon?
  - The MRSSM
- Sgluon couplings
- Sgluon production and decay
- Signals at the LHC
- Outlook

What is a sgluon?

- A sgluon is a scalar gluon.
  - An electrically neutral, color octet, spin 0 particle.
- Such objects have been studied in the past as arising from two (or more) UEDs - "spinless adjoints".

Dobrescu, Kong, Mahbubani

- I'm interested in a different context, with different phenomenology. Sgluons are extra states that appear in a supersymmetric theory with a Dirac gluino mass.

"Supersoft" - Fox, Nelson, Weiner

MRSSM

- Last year, an R-symmetric version of the minimal supersymmetric Standard Model appeared. Kribs, Poppitz, Weiner
- The R-symmetry turns out to be very useful in order to help with the SUSY flavor problem.

Majorana gluino

$$\frac{1}{m_{\tilde{g}}}\tilde{s}_L^*\tilde{d}_R \quad \bar{d}_R s_L \longrightarrow \frac{1}{m_{\tilde{g}}^2}\tilde{s}_L^*\partial_\mu\tilde{d}_L \quad \bar{d}_L\gamma^\mu s_L$$

Dirac gluino

Dimension 5 Dimension 6

- Relatively flavor-mixed squark masses become compatible with measurements of flavor-violation.
- Also see Andrew's talk coming up later this week!

Amigo, Blechman, Fox, Poppitz

Dirac Gauginos

- Majorana gaugino masses violate the R-symmetry.
- The solution is to enlarge the theory to include enough degrees of freedom for a Dirac gaugino by adding adjoint chiral super-multiplets.

$$R_\Phi = 0$$

$$\Phi^a = \phi^a + \sqrt{2}\theta\psi^a + \theta^2 F_\Phi$$

A sgluon!

Fox, Nelson, Weiner

- A D-term source of SUSY-breaking results in Dirac gaugino masses:

$$\int d^2\theta \frac{\sqrt{2}}{M} W' W_3^a \Phi^a \to m_{\tilde{g}} \lambda^a \psi^a + \ldots$$

$$\langle W' \rangle = D\theta \qquad m_{\tilde{g}} = \frac{D}{M}$$

SUSY Breaking

- Since Φ contains a complex scalar, technically we actually have two (real) sgluons.
- They gain mass directly from either D-term or F-term SUSY-breaking spurions: $\langle X \rangle = \theta^2 F$

$$\int d^4\theta \left\{ \frac{1}{M_1^2} X^\dagger X \Phi^\dagger \Phi + \frac{1}{M_2^2} X^\dagger X \Phi^2 \right\} + \int d^2\theta \frac{1}{M_3^2} W'_\alpha W'^\alpha \Phi^2 + H.c.$$

- These operators induce both φ^2 as well as $|\varphi|^2$ mass terms, generically splitting the complex scalar into two real mass eigenstates.

D-terms

- The gluino mass operator also contributes through the SU(3) D-term (remember the ...s):

$$\int d^2\theta \frac{\sqrt{2}}{M} W' W_3^a \Phi^a \rightarrow \ldots + \sqrt{2} D^a \left(m_{\tilde{g}} \phi^a + m_{\tilde{g}}^* \phi^{a*} \right)$$

- Going on-shell (integrating out the D-terms) produces more of the same types of masses, and interactions:

$$\frac{1}{2} D^a D^a + \sqrt{2} D^a \left(m_{\tilde{g}} \phi^a + m_{\tilde{g}}^* \phi^{a*} \right) + D^a g_S \sum \tilde{q}^* T^a \tilde{q}$$

Usual SU(3) D-terms

$$\rightarrow \quad m_{\tilde{g}}^2 \phi^2 + m_{\tilde{g}}^{2*} \phi^{*2} + |m_{\tilde{g}}|^2 |\phi|^2 + \sqrt{2} g_S \left(m_{\tilde{g}} \phi^a + m_{\tilde{g}}^* \phi^{a*} \right) \left(\sum \tilde{q}^* T^a \tilde{q} \right) + \ldots$$

More sgluon mass terms

Interactions with squarks

Sgluon Masses

- We've learned that sgluons typically get masses from SUSY-breaking of order the gluino mass.
- However, I can play the other soft masses against those contributions and really end up with anything I want. So I will lump them all together and call them parameters in their own right:

$$\mathcal{L}_{mass} = -m_1^2 \ |\phi^a|^2 - \frac{1}{2}|m_2^2|e^{i\gamma} \ \phi^{a2} - \frac{1}{2}|m_2^{*2}|e^{-i\gamma} \ \phi^{a*2}$$

- The mass eigenvalues are:

$$m^2_{\phi_1,\phi_2} = m_1^2 \mp |m_2^2|$$

- Eigenstates:

$$\phi_1^a = \sin\frac{\gamma}{2} \ \phi^a + \cos\frac{\gamma}{2} \ \phi^{a*}$$

$$\phi_2^a = \cos\frac{\gamma}{2} \ \phi^a - \sin\frac{\gamma}{2} \ \phi^{a*}$$

I'll just take $\gamma = 0$ from here on...

Sgluon Couplings

- Sgluons are color octets, and thus have interactions with gluons entirely determined by $SU(3)_C$ (SUSY) gauge invariance:

$$(D_\mu \phi)^* (D^\mu \phi) + i\sqrt{2} g_S f^a_{bc} \, \bar{\tilde{g}}^b \left(\phi^a P_L + \phi^{a*} P_R\right) \tilde{g}^c$$

  - Thus, they can be pair-produced in a model-independent way at the LHC.

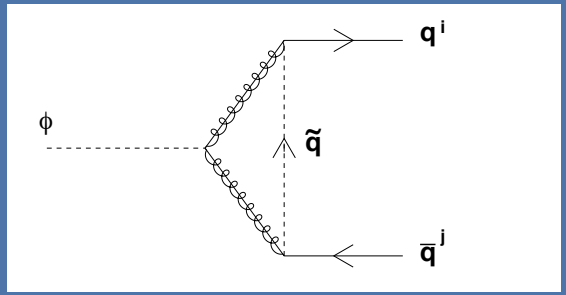
- No renormalizable supersymmetric interactions can couple the sgluon to matter fields.

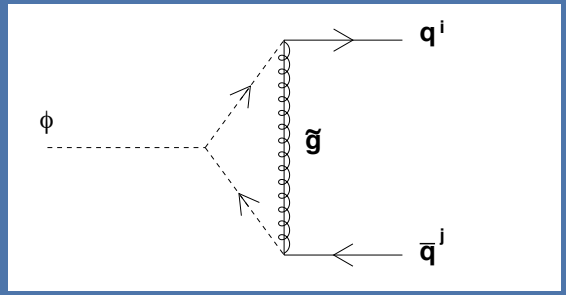
Coupling to Quarks

- Being R-charge 0, nothing stops the sgluons from coupling to pairs of ordinary quarks.
- However, the gauge-invariant interaction is a higher dimensional operator:

$$\phi^a \left[(H \bar{q}_L) T^a q_R \right] + H.c.$$

- Loops containing gluinos and squarks will induce this operator in the MRSSM.
- Chirality demands a gluino mass insertion in the first graph. The second graph is already proportional to the gluino mass, as we already saw.





Coupling to Quarks

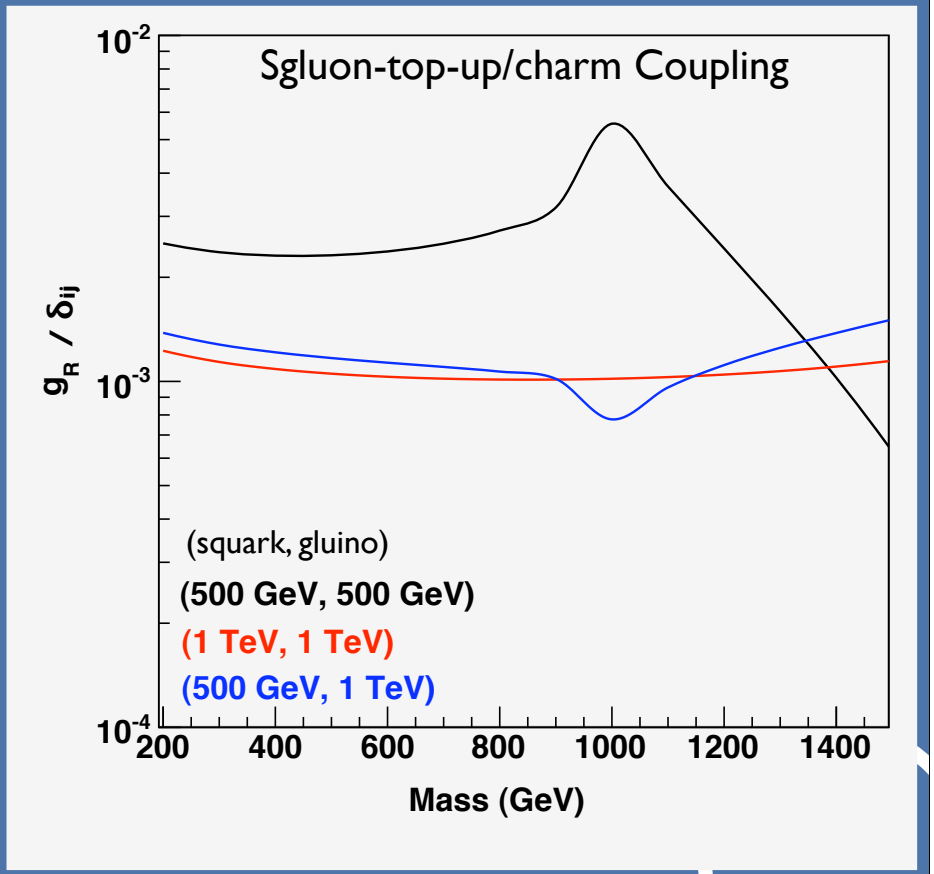
- We need one quark mass insertion. Interactions involving at least one top are preferred.

$$\sqrt{2}g_S^3 N_C m_{\tilde{g}} m_t C_{11}\left(m_t^2, 0, M^2; m_{\tilde{g}}, m_{\tilde{q}}, m_{\tilde{g}}\right)$$

$$-\sqrt{2}g_S^3 \frac{1}{N_C} m_{\tilde{g}} m_t \left[C_{11}\left(m_t^2, 0, M^2; m_{\tilde{q}}, m_{\tilde{g}}, m_{\tilde{q}}\right) + C_0(...)\right]$$

- The other quark can be either up or charm, with no penalty other than the squark mixing parameters.
- In the MRSSM we expect reasonably large squark mixing, so relatively large coupling to:

$$t\bar{t},\ t\bar{u},\ t\bar{c}, u\bar{t},\ c\bar{t}$$



Sgluon Decays

- Thus, sgluons are going to prefer to decay into top quarks.
- Assuming (in the spirit of the MRSSM) that the up-charm-top mixings are all large, there should be comparable branching ratios into top + up or charm as well.

Flavor-conserving pheno:
Dobrescu, Kong, Mahbubani

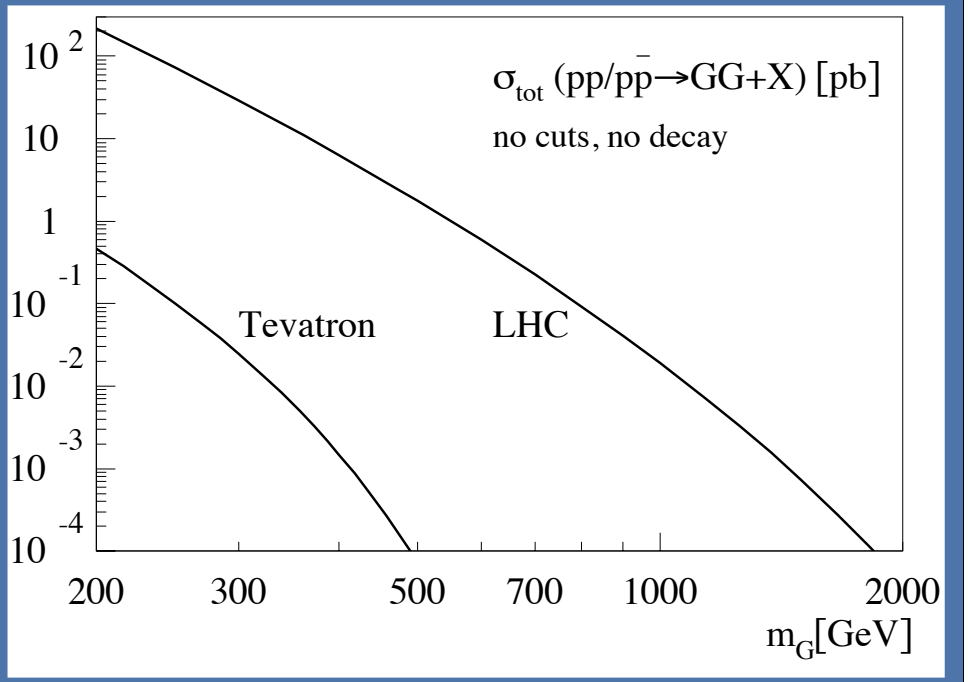
- Sgluons carry no charge or fermion number. They will have large branching ratios into:

$$t\bar{t},\ t\bar{u},\ t\bar{c}, u\bar{t},\ c\bar{t}$$

A pair of sgluons can give like-sign tops! (or four tops)

Pair Production

- Pair production rates depend only on the mass of the sgluon (the couplings are g_S).
- There are events for masses up to about 400 GeV (Tevatron) and 2 TeV (LHC).
- Single production from quarks is extremely tiny because of the small, loop-induced coupling strength.



A promising signature: 2 like-sign tops (with 2 jets) with the tops decaying to e or μ.

(Arvind told us about this class of signatures yesterday!)

Tevatron Limits

Bar-Shalom, Rajaraman, Whiteson, Yu

When he suggested we take out our iPhones and photograph the CDF limits, I'm not sure he really thought anyone would take the invitation literally...

Sgluon Signatures

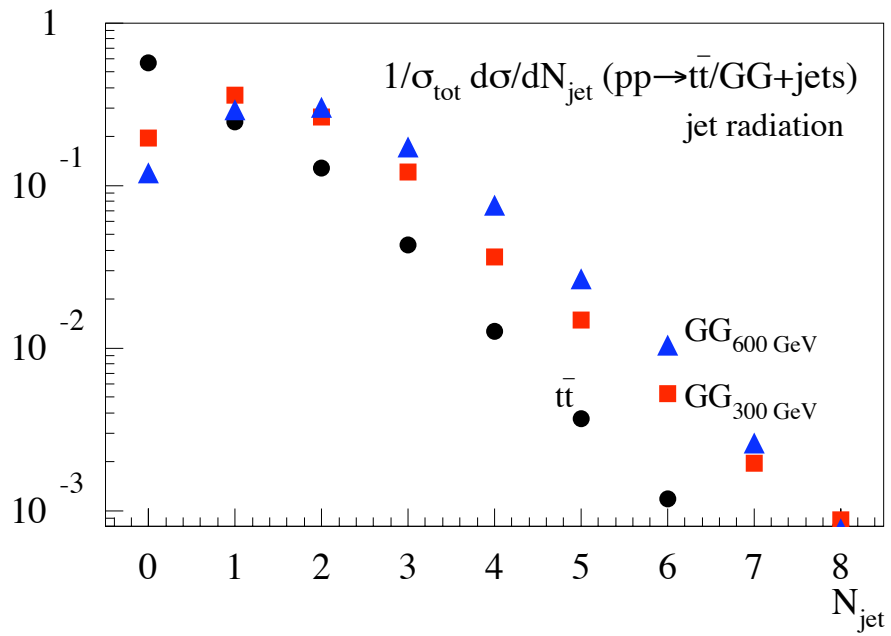
- We are still finalizing our analysis.
- Options include:
  - Flavor-violating decays, resulting in two tops and two jets.
    - Like-sign tops revealed through leptonic top decays
    - Lepton+jets top decays to reconstruct at least one sgluon.
  - Flavor-conserving decays into four tops total.
    - Again, like-sign top signatures.

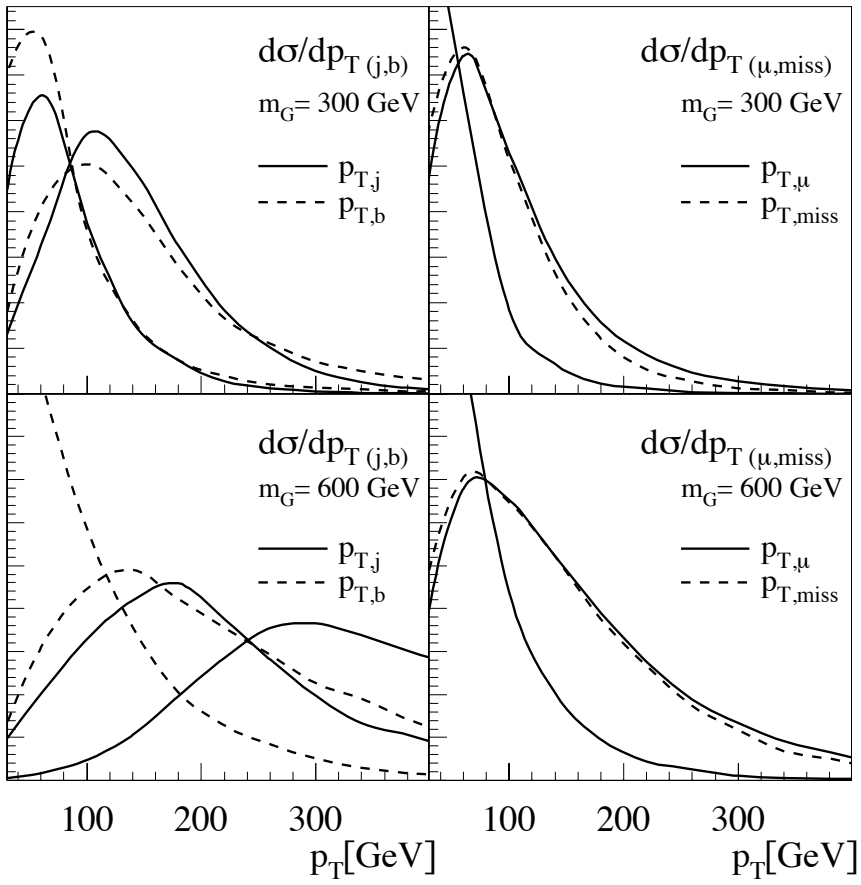
Also from top compositeness: Lillie, Shu, Tait

- Sgluon masses up to order 1 TeV should be discoverable.

Signal and Background

- We include the effects of QCD radiation through MLM matching to signal and t tbar background. (Thanks MadEvent...)





Outlook

- Sgluons are cool!
- They are a generic signature of a model with Dirac gaugino masses, and an essential feature of the MRSSM.
- They can have highly flavor-violating couplings, and prefer to decay into at least one top.
  - Their Branching Ratios tell us something about sfermion mixing.
- As color octets, there is large QCD pair production, resulting in like-sign top quarks at the LHC.